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D. M. BEACH, *Editor*

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The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

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STUDIES OF WATER-RETENTIVE CHEMICALS AS ADMIXTURES WITH NONPLASTIC ROAD-BUILDING MATERIALS

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by E. A. WILLIS, Associate Highway Engineer, and C. A. CARPENTER, Associate Civil Engineer

DURING the past several years the Public Roads Administration has conducted laboratory and field studies of various types of base-course materials and the factors that influence their behavior in service. The results of two of the laboratory investigations have been published in recent issues of PUBLIC ROADS.[1]

Observation of the behavior of soil road surfaces and the performance of the same materials following the application of bituminous surfaces has suggested the need for laboratory study of this type of construction. Such observations have already established the following facts:

1. Mixtures of granular aggregate and clay binder that form highly stable road surfaces may become unstable as bases when covered with a waterproof surfacing.
2. Nonplastic granular materials, having gradings within definitely established limits, provide stable base courses for relatively thin bituminous surface treatments.
3. These same nonplastic materials when subjected to traffic prior to surface treatment may be loose and dusty in dry weather and the loss of surface metal may be excessive.
4. Moisture films serve to bind such nonplastic aggregates into a coherent road surface.
5. Certain chemicals used either as admixtures or surface applications aid materially in maintaining these moisture films under suitable climatic conditions.

This report describes investigations using the outdoor circular track, shown in figure 1, to determine the effect of the water-retentive chemicals, calcium chloride and sodium chloride, on nonplastic granular mixtures under controlled traffic and moisture conditions both before and after the application of a thin bituminous surface treatment.

The circular track used in these investigations was, with the exception of tire equipment, a duplicate of the indoor track used in the studies previously reported.[1] The test wheels for the outdoor setup were equipped with high-pressure tires, size 30×5, requiring an inflation pressure of 80 pounds per square inch instead of the size 6.00–20 low-pressure tires that were used with the indoor equipment. The load was, as in the indoor track tests, 800 pounds on each wheel. This was increased to 1,000 pounds near the end of some of the tests.

Distributed traffic which was used for compacting and testing the unsurfaced mixtures was obtained by gradually shifting the rotating beam longitudinally with respect to its axis of rotation, causing the wheels to pursue alternately expanding and contracting spiral courses covering the entire track area. Concentrated traffic, which was used after the surface treatment had been constructed, was obtained by locking the sliding pivot of the beam in such a position that the wheels pursued two concentric circular courses whose center lines were about 2½ inches on either side of the center line of the track.

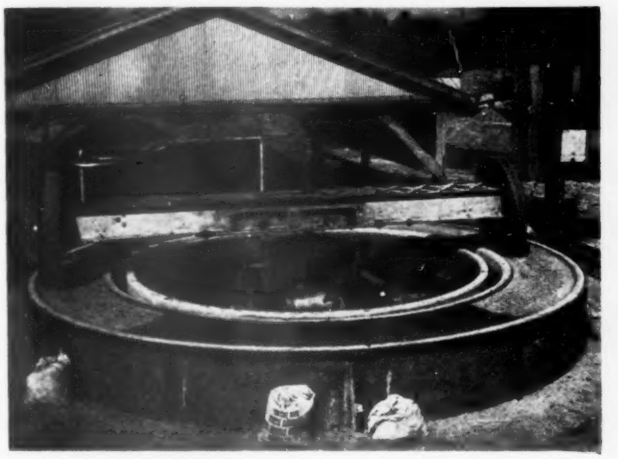

FIGURE 1.—THE OUTDOOR CIRCULAR TRACK USED IN TESTING ROAD-BUILDING MATERIALS. IN THE BACKGROUND IS THE MOVABLE SHED USED TO COVER THE TRACK AT NIGHT AND DURING RAINY WEATHER.

This investigation involved the construction and testing of 20 track sections. Each section was 18 inches wide, 6 inches deep, and approximately 7.5 feet long. Five sections comprised a test track and were tested as a group. Thus four tracks were required to test the 20 sections.

VARIOUS AGGREGATES AND ADMIXTURES USED IN TEST SECTIONS

The gradings and soil constants of the aggregates used in the 20 test sections are given in table 1. The materials comprising the 15 test sections of tracks 1, 2, and 3 were prepared by combining Potomac River gravel, Potomac River sand, pulverized silica, and a local clay soil having a liquid limit of 41 and a plasticity index of 18.

Crusher-run limestone, blast-furnace slag, and granite were used in the construction of the five sections tested in track 4.

Tracks 1, 2, and 3, except for minor differences in grading incident to slight variations in the stock materials, had identical composition. In section 1 of each of the three tracks the material passing the No. 200 sieve was primarily the clay soil while in all other sections the fines consisted primarily of the inert pulverized silica. Sections 1 and 2 of tracks 1, 2, and 3, had approximately the same amounts of material passing the No. 200 sieve. Sections 3, 4, and 5, differed from sections 1 and 2 and from each other primarily in the amount of mineral dust present.

[1] A study of Sand-Clay Materials for Base-Course Construction, by C. A. Carpenter and E. A. Willis. PUBLIC ROADS, November 1938. A study of Sand-Clay-Gravel Materials for Base-Course Construction, by C. A. Carpenter and E. A. Willis. PUBLIC ROADS, March 1939.

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TABLE 1.—*Gradings and soil constants of materials used in study of water-retentive chemicals*

	Track No. 1, section—					Track No. 2, section—					Track No. 3, section—					Track No. 4, section—				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Grading:	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Passing 1-inch sieve	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Passing ¾-inch sieve	98	98	95	96	97	98	96	97	97	98	96	92	97	93	97	100	100	100	100	100
Passing No. 4 sieve	75	80	66	69	63	76	73	67	62	58	79	67	56	61	59	98	94	65	98	95
Passing No. 10 sieve	62	69	57	59	52	65	64	56	50	46	66	59	48	50	46	55	63	35	64	56
Passing No. 40 sieve	40	46	37	35	31	40	43	35	30	26	45	41	33	30	29	25	43	19	41	37
Passing No. 200 sieve	23	24	18	12	9	23	26	19	12	7	25	22	16	12	9	12	16	5	16	14
Passing 0.005 mm	7	6	5	4	4	8	8	6	5	5	11	5	4	3	3	3	3	1	3	2
Dust ratio [1]	58	52	49	34	29	58	60	54	40	27	56	54	48	40	31	48	37	26	39	38
Tests on material passing No. 40 sieve:																				
Liquid limit	17	17	18	16	18	18	17	16	15	16	17	14	14	13	10	14	15	27	25	25
Plasticity index	2	0	0	0	0	3	2	2	0	0	2	0	0	0	0	2	0	0	0	0

[1] Dust ratio $=100\left[\frac{\text{percentage passing No. 200 sieve}}{\text{percentage passing No. 40 sieve}}\right]$.

In track 4, section 1 consisted of limestone, section 2 of granite, section 3 of blast-furnace slag, section 4, 90 percent by weight of granite and 10 percent slag, and section 5, 90 percent by weight of granite and 10 percent limestone.

Calcium chloride was used as an admixture in track 1 and sodium chloride in track 2. Track 3 was tested without a chemical admixture. Track 4 was tested first without chemical treatment and then with a surface application of calcium chloride.

In constructing the test sections of tracks 1, 2, and 3, sufficient water including that used to dissolve the chemicals was added to the aggregates to bring the mortar portion to its optimum moisture content as previously determined by the Proctor test (A. A. S. H. O. Standard Compaction Test No. T99–38) with a slight excess for wetting the coarse aggregate.

No Proctor compaction tests were made on the crusher-run materials used in track 4. Just enough water was combined with the mixtures used in this track to cause them to hold a cast when squeezed in the hand. Vibratory compaction [2] tests were made on these materials subsequent to the construction of the sections.

The moisture contents of all sections immediately after being placed in the track and the optimum moisture contents for the mortars of the materials used in tracks 1, 2, and 3, are shown in table 2.

The procedures for preparing the materials for the track tests, constructing the test sections, and surface-treating them were as follows:

1. Sufficient materials were prepared for only one track at a time. The aggregates were proportioned by weight from the stock materials to give the desired gradings and were thoroughly mixed before any water was added.
2. Water was added and mixing continued to distribute the moisture.
3. In tracks 1 and 2, the chemical admixture, in the amount of 2 pounds per square yard, was added as a solution along with the water.
4. The moistened mixtures were then placed in the trough of the track in two approximately equal layers, each layer being compacted with the traffic of pneumatic-tired wheels uniformly distributed over the surface.
5. Compaction was continued on the top layer until no further subsidence was noted and all sections were in suitable condition for testing. This required 18,200 wheel-trips, 64,000 wheel-trips, 60,000 wheel-trips, and 82,600 wheel-trips for tracks 1, 2, 3, and 4, respectively.
6. Testing of the materials without a bituminous surface treatment then proceeded.
7. After this phase of the testing had been completed, the sections were reshaped and trimmed smooth.
8. A prime consisting of 0.3 gallon per square yard of light tar was applied and allowed to cure.
9. A surface treatment consisting of 0.4 gallon of hot application bituminous material and a cover of 50 pounds per square yard of stone of ¾-inch maximum size was constructed.
10. The treatment was consolidated by additional distributed traffic until the surface was well sealed and showed no movement.

[2] A New Vibratory Machine for Determining the Compactibility of Aggregates, by J. T. Pauls and J. F. Goode, PUBLIC ROADS, May 1939.

TABLE 2.—*Moisture contents immediately after construction and optimum moisture contents on the fraction of material passing the No. 10 sieve*

Track No.	Section No.	Moisture content of sections after placing [1]	Optimum moisture content of material passing No. 10 sieve [2]
		Percent	*Percent*
1	1	8.6	9.8
	2	6.9	9.8
	3	7.0	8.6
	4	6.2	9.1
	5	6.9	9.0
2	1	7.1	10.0
	2	6.4	9.5
	3	6.6	9.5
	4	5.4	8.9
	5	4.3	8.6
3	1	6.9	10.0
	2	6.2	10.3
	3	5.3	9.7
	4	4.8	9.8
	5	4.3	9.1
4	1	6.7	
	2	10.0	
	3	8.0	
	4	9.6	
	5	11.2	

[1] Based on the dry weight of the total aggregate.
[2] Based on the dry weight of the portion of the aggregate passing the No. 10 sieve.

WEATHER CONDITIONS VARIED CONSIDERABLY DURING TEST

The outdoor track was used in these investigations because it was desired to subject the materials treated with water-retentive chemicals to the influence of changes in temperature and humidity similar to those encountered on roads in service. A recording thermometer and hygrometer was installed near the track to determine these factors. A movable sheet metal roof, shown in figure 1, was used to cover the track at night and on rainy days so that the amount of water placed on the surface of each section could be accurately controlled.

The tests described in this report were conducted at different times of the year. A brief summary of the temperature and humidity data collected by means of the recording instrument, previously mentioned, during the tests on the four tracks is presented in table 3.

The behavior of the materials under test was judged on the basis of the appearance of the sections at various stages of the tests supplemented by measurements of vertical displacement of the surface. The measurements were made with the transverse and longitudinal profilometers which have been described in the previous reports.

TABLE 3.—*Summary of weather data*

	Track No. 1	Track No. 2	Track No. 3	Track No. 4
Date constructed	7-15-36	10-19-36	4-12-37	10-8-37
End of test	10-12-36	4- 3-37	6-11-37	4-2-38
Average daily maximum temperature ° F.	83.3	51.0	75.2	52.1
Average daily minimum temperature ° F.	62.1	32.0	51.7	31.9
Maximum recorded temperature ° F.	101	81	93	86
Minimum recorded temperature ° F.	42	16	32	16
Greatest change in 24 hours:				
From ° F.	101	69	93	74
To ° F.	67	31	42	29
Average daily maximum relative humidity percent	88.4	81.0	84.0	82.8
Average daily minimum relative humidity percent	35.8	31.0	26.0	39.1
Maximum recorded relative humidity percent	94	93	92	93
Minimum recorded relative humidity percent	14	9	9	6
Greatest change in 24 hours:				
From percent	90	90	92	92
To do	14	10	9	8

The resistance to raveling of the various materials when tested without the protective surface treatment was judged primarily by visual observation. No close correlation could be obtained between vertical displacement and the time raveling started because the concrete curbs prevented much of the loosened material from being thrown off the surface. During the portion of the test period in which water was sprinkled on the surface, increasing rates of vertical displacement were observed in some instances even though during this stage the surface was generally well bonded and in good condition.

An average vertical displacement of about 0.25 inch, measured after the sections had been surface treated and subjected to the action of concentrated traffic, was observed to be sufficient to cause noticeable damage to the bituminous surface. This is in agreement with conclusions reached in previous investigations using the same apparatus. Numerically, the amount of rutting measured with the longitudinal profilometer agreed in general with the amount of vertical displacement measured with the transverse profilometer.

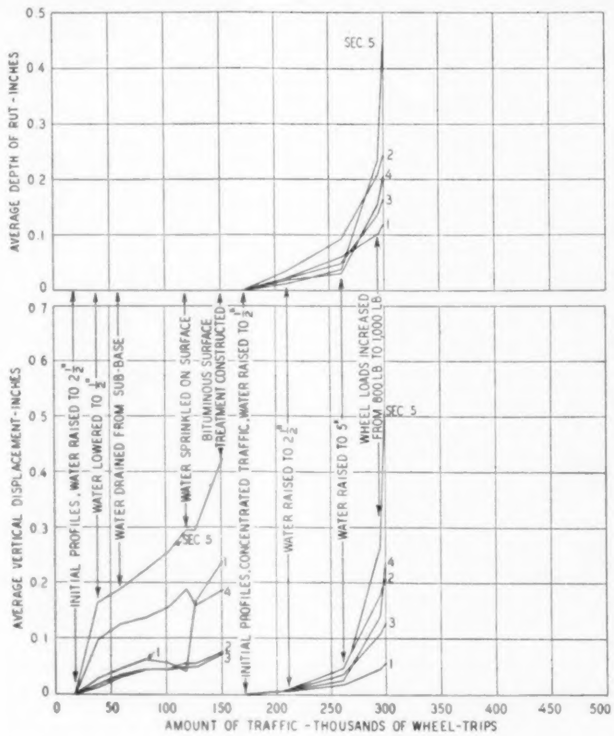

FIGURE 2.—SURFACE DISPLACEMENTS OF SECTIONS OF TRACK 1 AT VARIOUS STAGES OF THE TEST.

Changes in behavior of the various sections under altered test conditions are clearly shown by abrupt changes in the slopes of the displacement curves in figure 2 for track 1 and in subsequent figures for tracks 2, 3, and 4.

Track 1: Calcium chloride admixture.—The schedule of traffic applications and changes in water elevation with notations on the behavior of the five test sections of track 1 are given in table 4.

Figure 2 shows the combined effect of consolidation and loss of surface material as measured by the transverse profilometer for the period up to 151,200 wheel-trips during which time the sections were being tested under distributed traffic, without bituminous surfaces. It also shows, for the period from 171,200 wheel-trips to the end of the test, the displacements of the sections as measured with both profilometers while testing under concentrated traffic, with bituminous surfaces.

TABLE 4.—*Schedule of operations and behavior of test sections in track 1 with calcium chloride*

Operation	Traffic	Water level above top of sub-base	Behavior				
			Sec. 1	Sec. 2	Sec. 3	Sec. 4	Sec. 5
	Wheel-trips	*Inches*					
Placing and compacting	0 to 18,200	[1] 0	Unstable	Good	Good	Good	Good.
Testing with distributed traffic	18,200 to 38,200	2½	Slightly unstable	do	do	do	Slight raveling.
Do	38,200 to 58,200	½	Good	do	do	do	Raveled.
Do	58,200 to 118,200	[1] 0	do	do	do	Slight raveling	Do.
Sprinkling and testing with distributed traffic.	118,200 to 151,200	[1] 0	Slightly unstable	do	do	Good during sprinkling, some raveling later.	Good during sprinkling, raveled later.
Compacting bituminous surface treatment.	151,200 to 171,200	[1] 0	Good	do	do	Good	Good.
Testing with concentrated traffic	171,200 to 211,200	½	do	do	do	do	Do.
Do	211,200 to 261,200	2½	do	do	do	do	Do.
Do	[2] 261,200 to 298,500	5	do	do	do	Slightly unstable	Unstable.

[1] No water in sub-base.
[2] Wheel loads increased from 800 to 1,000 pounds at 295,000 wheel-trips.

Loosening of the surface metal under distributed traffic was first noted at about 35,000 wheel-trips in section 5, which was the section having the lowest percentage of No. 200 material. At this time the water was 2½ inches above the bottom of the test layer. Traffic was continued and the water level lowered (see table 4) until the base was finally drained. Raveling progressed in section 5 until, at 118,200 wheel-trips, the surface was quite loose and open as shown in figure 3. A similar action in lesser degree was noted in section 4.

FIGURE 3.—TYPICAL SECTIONS OF TRACK 1 AT 118,200 WHEEL-TRIPS, JUST BEFORE THE FIRST SPRINKLING. LEFT, SECTION 2, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 1 AND 3; RIGHT, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTION 4.

Sections 2 and 3 remained in good condition throughout this portion of the test. Section 1 failed to compact well during the initial compaction period (0 to 18,200 wheel-trips) but began to set up soon after water was admitted to the sub-base and exhibited no signs of excessive raveling from about 38,000 wheel-trips to 118,200 wheel-trips, when the track was first sprinkled. Figure 3 shows section 2 at 118,200 wheel-trips. Sections 1 and 3 were in a similar condition at this time. Some exposed aggregate was evident, particularly along the curb lines where abrasion was most severe, but in general the surfaces were dense and well bonded.

LEACHING TESTS ON TRACK 1 STARTED AT 118,200 WHEEL-TRIPS

Water was applied to the surface of the test sections in track 1 during the traffic test period from 118,200 to 129,600 wheel-trips in the following manner:

1. Temporary dikes of plastic clay were placed at the ends of each section.
2. Water was sprinkled on the surface in increments equivalent to one-fourth inch of rainfall distributed over the area of each section.
3. The water was allowed to soak into the respective sections and to percolate through the test course, into the sub-base, and out the drains at the bottom.
4. After each of the first six applications of water had disappeared from the surface the dikes were removed and about 2,000 trips of test traffic applied.

Nine applications of water or the equivalent of 2¼ inches of rainfall were allowed to percolate down through the test course and six increments of traffic, 11,400 wheel-trips in all, were applied, bringing the total traffic to 129,600 wheel-trips.

The first application of water disappeared from the surface of section 5 in about 2 hours, and about 24 hours were required for the water to disappear completely from section 1. The time required for the water to enter the mixtures became progressively greater with each increment of water until toward the end of this phase of the test, 24 hours was required for section 5 to transmit a ¼-inch application of water.

Samples were taken from each section near the centerline just before the first application of water (118,200 wheel-trips) and again after the final application had leached through all sections. These samples were obtained by boring through the entire thickness of the test layer with a 1½-inch soil auger. Care was taken to save all the material from the test holes, which were made as nearly uniform in cross section throughout their depth as possible. The moisture content of each section as well as the calcium chloride content recovered from that portion of each boring passing the No. 10 sieve are shown in table 5 for the times indicated above as well as at the beginning and end of the test.

TABLE 5.—*Moisture contents and calcium chloride contents in track 1 at several stages of the test*

Section No.	Number of wheel-trips	Stage of test	Moisture content based on dry weight	Calcium chloride content of portion passing No. 10 sieve
			Percent	*Percent*
1	2,700	Start	8.6	0.22
	118,200	Before sprinkling	1.7	1.11
	129,600	After sprinkling	4.5	.32
	298,500	After testing with bituminous surface	5.6	.17
2	2,700	Start	6.9	.19
	118,200	Before sprinkling	1.3	.33
	129,600	After sprinkling	3.7	.08
	298,500	After testing with bituminous surface	5.3	.05
3	2,700	Start	7.0	.22
	118,200	Before sprinkling	1.4	.20
	129,600	After sprinkling	4.1	.11
	298,500	After testing with bituminous surface	4.6	.03
4	2,700	Start	6.2	.26
	118,200	Before sprinkling	1.4	.06
	129,600	After sprinkling	3.3	.05
	298,500	After testing with bituminous surface	5.7	0
5	2,700	Start	6.9	.27
	118,200	Before sprinkling	1.3	.06
	129,600	After sprinkling	3.2	.12
	298,500	After testing with bituminous surface	5.9	0

Tests on the mortar portion of the five mixtures just before laying showed calcium chloride contents of 0.19 to 0.27 percent of the dry weight of the fraction passing the No. 10 sieve. After 118,200 wheel-trips, the samples showed calcium chloride contents in the mortar portion of 1.11 percent for section 1, and 0.33 percent for section 2. The percentages of calcium chloride in the other sections at this time were less than at the start of the test, being 0.20 percent for section 3, and 0.06 percent for both sections 4 and 5.

Sections 1 and 2, which showed marked increases in chloride content along the center line, were denser and had higher dust contents than sections 3, 4, and 5. As will be shown later even greater increases were observed in sections 1 and 2 of track 2 in which sodium chloride was used as an admixture. There was nothing disclosed by the tests to explain these increases.

The effect of leaching on the chloride content is clearly shown in table 5. All sections except section 5 showed a decrease in the amount of the soluble salt present. Further decreases in chloride content were revealed by analyses made at the end of the test period. The retention of the admixture was greatest in section 1 which contained the clay-soil and decreased as the amount of material passing the No. 200 sieve decreased.

After the final application of water on the surfaces of the test sections, distributed traffic was continued to 151,200 wheel-trips with no water in the sub-base. During this period section 1, which had showed signs of surface rutting when saturated from the top, became stable again although the accumulated average vertical displacement had reached 0.24 inch before the surface treatment was applied. Sections 2 and 3 showed little movement and were not affected by the water applied to the surface. Sections 4 and 5 appeared to be benefited temporarily by the surface applications of water. Their surfaces became smooth and well bonded under the action of traffic. This improvement, although of very short duration, is shown by the temporary change in slope of their vertical displacement curves (fig. 2). As traffic was continued under drying conditions the previous tendency of these two sections to ravel reappeared. Figure 4 illustrates the appearance of typical sections of track 1 at 151,200 wheel-trips, or just before the bituminous surfaces were applied. The view of section 2 is representative of the condition of sections 1, 2, and 3. That of section 5 is representative of the condition of sections 4 and 5, and shows the decidedly loose and open-surface texture of these two sections.

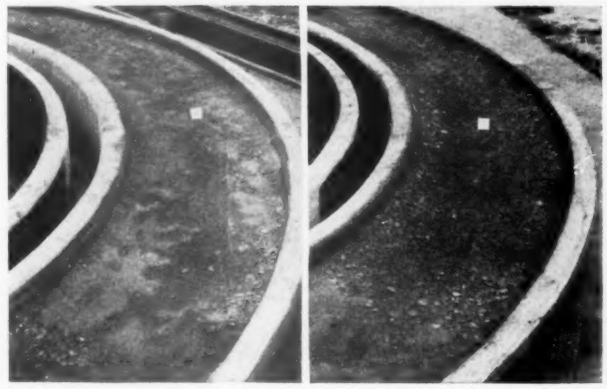

Figure 4.—Typical Sections of Track 1 at 151,200 Wheel-Trips, Just Before Construction of the Bituminous Surface. Left, Section 2, Which Is Also Representative of Sections 1 and 3; Right, Section 5, Which Is Also Representative of Section 4.

TRAFFIC TESTS CONTINUED AFTER BITUMINOUS SURFACE APPLIED

As shown in figure 2, new initial or zero displacement readings were taken after the application and compaction of the bituminous surface and the record from that time on or from 171,200 wheel-trips to the end of the test indicates the behavior of the chemically treated materials when acting solely as base courses.

The materials in all sections of track 1 gave good service and showed little movement as base courses even under the very severe test conditions imposed by maintaining the water elevation at 2½ inches. At 261,200 wheel-trips, or 90,000 wheel-trips after the start of concentrated traffic and 60,000 wheel-trips after the water had been raised to the 2½-inch level, the average vertical displacement of the surface on all the sections was less than 0.05 inch and the maximum amount of rutting was 0.09 inch. It was not until the water had been raised to the 5-inch level, or to within 1 inch of the bituminous surfacing, that pronounced base movement was observed. Under this extreme condition and with increased wheel loads, section 5 had definitely failed at the end of the test, 298,500 wheel-trips. Section 4 exhibited considerable movement and the surface treatment between the wheel courses was cracked. The wheel tracks were visible on sections 1, 2, and 3, but there was little distortion of the surface treatment. The condition of the track at the end of the test is shown in figure 5. The final condition of sections 2 and 3 was similar to that of section 1.

Track 2: Sodium chloride admixture.—This track consisted of five mixtures similar to those tested in track 1.

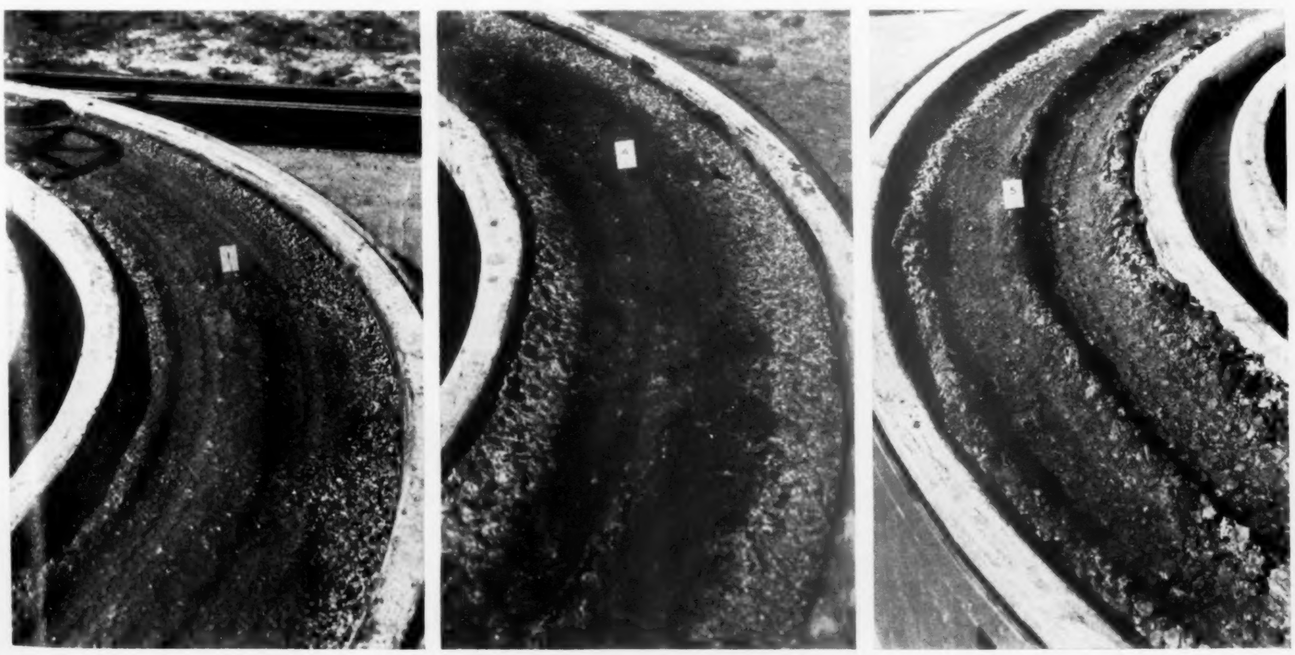

Figure 5.—Sections of Track 1 at the Conclusion of the Test. Left, Section 1, Which Is Also Representative of Sections 2 and 3; Middle, Section 4; Right, Section 5.

The test schedule together with notations on the behavior of the five test sections are given in table 6. Figure 6 shows the results of the displacement measurements.

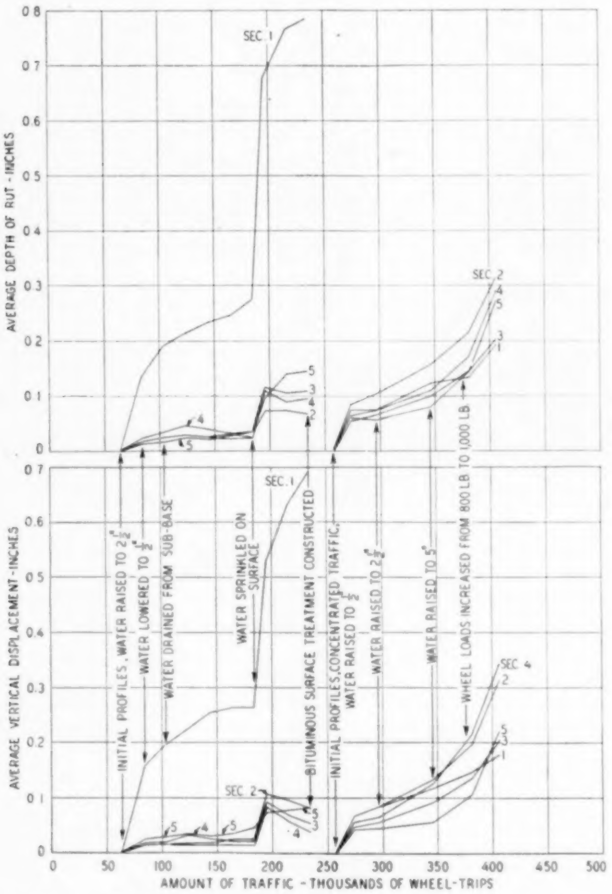

Figure 6.—Surface Displacements of Sections of Track 2 at Various Stages of the Test.

Raveling of the surface under distributed traffic was first noted at about 160,000 wheel-trips in section 5 and progressed gradually to 184,000 wheel-trips, when sprinkling was started. At this time sections 2, 3, and 4 had also started to ravel to some extent along the curb line. The condition of section 5 is illustrated in figure 7.

Figure 7.—Section 5 of Track 2 at 184,000 Wheel-Trips, Just Before the First Sprinkling. Some Raveling Had Developed, Particularly Along the Edges.

The average vertical displacement of sections 2, 3, 4, and 5 was less than 0.05 inch and the amount of rutting was correspondingly low. Section 1 of track 2 failed to compact readily as was the case with the corresponding section in track 1. In track 2, this section finally became stable at about 84,000 wheel-trips although the rate of average vertical displacement continued to be much higher than in the other sections up to about 150,000 wheel-trips. Thereafter little additional movement was noted until water was applied to the surface.

Sprinkling was started at 184,000 wheel-trips and continued in a manner similar to that described for track 1. The water passed through the salt treated sections slowly. The first application was made on a Saturday and had all disappeared by the following Monday. The second application required about 24 hours to disappear from section 5 and between 32 and 48 hours to disappear from the other sections. Four days after the last application there was still some water remaining on sections 1 and 2 in the low spots.

The moisture content of each section as well as the sodium chloride content determined on that portion of

Table 6.—*Schedule of operations and behavior of test sections in track 2 with sodium chloride*

Operation	Traffic	Water level above top of sub-base	Behavior				
			Sec. 1	Sec. 2	Sec. 3	Sec. 4	Sec. 5
	Wheel-trips	*Inches*					
Placing and compacting	0 to 64,000	[1] 0	Unstable	Good	Good	Good	Good.
Testing with distributed traffic	64,000 to 84,000	2½	Slightly unstable	do	do	do	Do.
Do	84,000 to 104,000	½	Slight pitting	do	do	do	Do.
Do	104,000 to 184,000	[1] 0	Good	Slight raveling	Slight raveling	Slight raveling	Raveled.
Sprinkling and testing with distributed traffic.	184,000 to 234,300	[1] 0	Slightly unstable	Good	Good	Good	Good during sprinkling but raveled later.
Compacting bituminous surface treatment.	234,300 to 257,000	[1] 0	Good	do	do	do	Good.
Testing with concentrated traffic	257,000 to 297,000	½	do	do	do	do	Do.
Do	297,000 to 347,000	2½	do	do	do	do	Do.
Do	[2] 347,000 to 407,000	5	do	Slightly unstable	Slightly unstable	Slightly unstable	Slightly unstable.

[1] No water in sub-base.
[2] Wheel loads increased from 800 to 1,000 pounds at 375,000 wheel-trips.

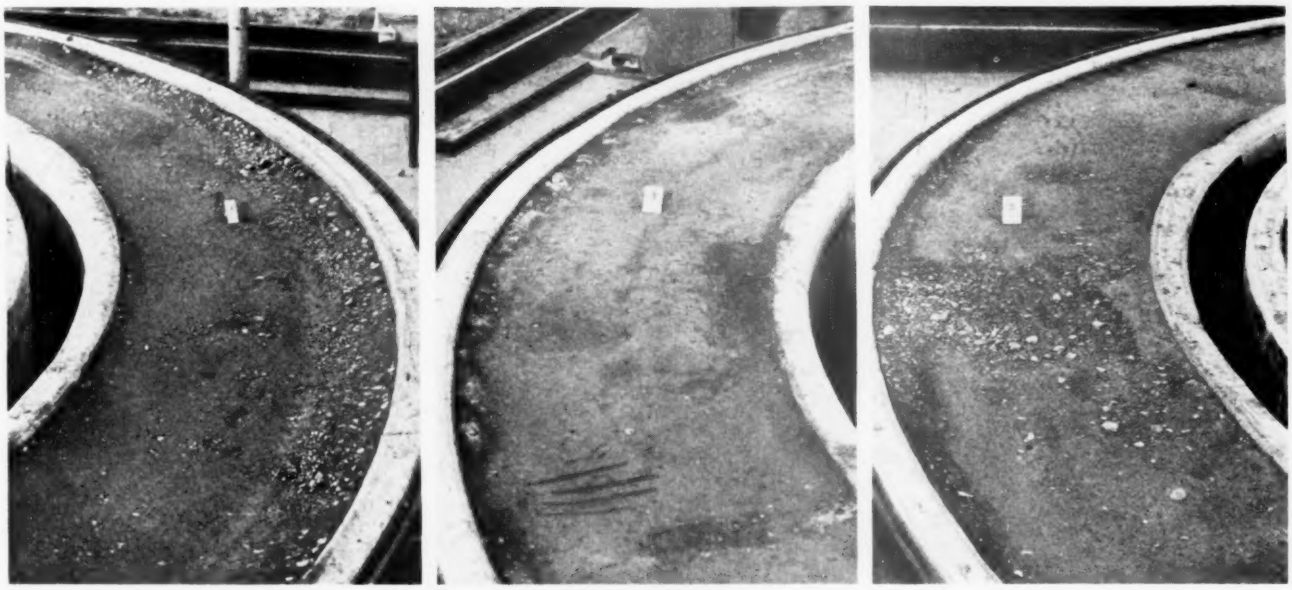

FIGURE 8.—SECTIONS OF TRACK 2 AT 234,300 WHEEL-TRIPS, JUST BEFORE CONSTRUCTION OF THE BITUMINOUS SURFACE. LEFT, SECTION 1; MIDDLE, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4; RIGHT SECTION 5.

the material passing the No. 10 sieve is shown in table 7 for various time during the testing period. The leaching effect is clearly illustrated in this table, being most pronounced in the sections with the lowest dust contents.

The sodium chloride contents of samples taken from sections 1, 2, and 5, were much greater at 184,000 wheel-trips than at the start of the track test. Section 3 showed a slight increase and section 4 a slight decrease

TABLE 7.—*Moisture contents and sodium chloride contents in track 2 at several stages of the test*

Section No.	Number of wheel-trips	Stage of test	Moisture content based on dry weight	Sodium chloride content of portion passing No. 10 sieve
			Percent	*Percent*
1	1,600	Start	7.1	0.24
	184,000	Before sprinkling	3.6	1.29
	196,000	After sprinkling	5.3	.21
	407,000	After testing with bituminous surface.	5.1	.16
2	1,600	Start	6.4	.31
	184,000	Before sprinkling	3.5	1.49
	196,000	After sprinkling	4.6	.11
	407,000	After testing with bituminous surface.	5.5	.07
3	1,600	Start	6.6	.23
	184,000	Before sprinkling	2.7	.35
	196,000	After sprinkling	3.9	.06
	407,000	After testing with bituminous surface.	4.3	.03
4	1,600	Start	5.4	.27
	184,000	Before sprinkling	2.6	.19
	196,000	After sprinkling	4.4	.17
	407,000	After testing with bituminous surface.	4.7	.03
5	1,600	Start	4.3	.18
	184,000	Before sprinkling	2.3	.43
	196,000	After sprinkling	3.3	.04
	407,000	After testing with bituminous surface.	5.1	.02

Distributed traffic was continued after the final application of water on the surface up to 234,300 wheel-trips. All sections showed a marked increase in the rate of vertical displacement after the application of water. Section 1 softened on the surface but did not become unstable throughout its entire depth. The excessive displacements measured on section 1 (see fig. 6) may be explained by the fact that the softened surface crust picked up under the wheels and was either deposited on other sections or thrown off the track.

The photograph of section 1, figure 8, taken at 234,300 wheel-trips, shows this condition. It can be seen that the surface is definitely lower than that of the adjoining section shown in the background although there are no indications of rutting.

Sections 2, 3, and 4 showed an increase in vertical displacement during the sprinkling operations but bonded firmly under distributed traffic and actually became smoother as the test progressed up to 234,300 wheel-trips or the end of this phase of the test as illustrated by the view of section 3 in figure 8.

Section 5 continued to show increasing amounts of vertical displacement both during and after the sprinkling operation and while this section was not loose during the time water was being applied, evidence of raveling was noted as drying started soon after the last application. This section is also shown in figure 8.

ALL MIXTURES IN TRACK 2 PROVED SATISFACTORY AS BASE COURSES

A bituminous surface treatment was applied to track 2 at 234,300 wheel-trips. All the mixtures proved satisfactory as base courses when treated with sodium chloride as they did in track 1 when treated with calcium chloride. Again it was necessary to raise the water table to the 5-inch level and increase the wheel loads to 1,000 pounds before definite indications of failure could be produced. The average vertical displacements and rutting (see fig. 6) varied from 0.04 to 0.09 inch for all sections between the time concentrated traffic was started at 257,000 wheel-trips and the time the second set of profiles was taken at 274,000 wheel-trips. Most of this displacement resulted from incomplete initial compaction of the surface treatment which was constructed in cold weather. Even with this displacement, which cannot be attributed to movement in the base, neither the average vertical displacements nor

FIGURE 9.—SECTIONS OF TRACK 2 AT THE CONCLUSION OF THE TEST. LEFT, SECTION 1; MIDDLE, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4; RIGHT, SECTION 5.

the average depth of ruts exceeded 0.25 inch for any of the sections until near the end of the test.

When the test was concluded at 407,000 wheel-trips, section 1 was in fairly good condition except for the superficial rutting caused by poor compaction of the surface treatment (fig. 9), and showed the least amount of displacement. Profilometer measurements indicated the greatest amounts of movement to have occurred in sections 2 and 4. The appearance of these two sections at the end of test was very similar to that of section 3, shown in figure 9. The surface treatment on all three of these sections had cracked between the wheel courses. Section 5 was showing signs of failure at the end of the test although the total vertical displacement was not as great as for some of the other sections. The surface treatment was breaking and the section was becoming rough generally as shown in figure 9.

Track 3: Without chemical admixture.—Five mixtures similar in composition to those placed in tracks 1 and 2 were tested in track 3 without the admixture of a water-retentive chemical.

The schedule of testing operations and observations on the behavior of the five sections of track 3 are given in table 8. Figure 10 shows the average vertical displacement and the amount of rutting.

In general, the behavior of the five materials without chemical admixture was conspicuously different from that of the corresponding sections of tracks 1 and 2 prior to the application of the surface treatment. Section 1 failed to compact well, as did the same section in the two previous tracks, showing considerable movement throughout the 60,000 wheel-trips of compacting traffic. It differed widely from the others, however, during the initial flooding of the sub-base from 60,000 to 100,000 wheel-trips. (See table 8.) The surface became dry and dusty, indicating that evaporation was proceeding at a faster rate than the water could be brought up through the material by capillarity. No such behavior was observed in tracks 1 and 2 where water-retentive chemicals were used as admixtures.

Raveling in section 1 began shortly after 80,000 wheel-trips when the water was dropped to one-half inch above the bottom of the test course. Shortly before the sub-base was drained at 100,000 wheel-trips, sections 2 and 3 also started to ravel in the order named. The surfaces of all three sections were dry at this time in contrast to the surfaces of sections 4 and 5 which appeared damp and well bonded.

SPRINKLING AIDED IN SURFACE MAINTENANCE OF GRANULAR MIXTURES

Upon the complete withdrawal of water from the sub-base, sections 4 and 5 also started to ravel. The condition of representative sections at 160,000 wheel-trips just prior to sprinkling is illustrated by figure 11. Section 1 is representative of the condition of both sections 1 and 2. Section 3 shown at the bottom of figure 11 was intermediate and sections 4 and 5 were in slightly better condition than section 3.

TABLE 8.—*Schedule of operations and behavior of test sections in track 3 without chemical admixtures*

Operation	Traffic	Water level above top of sub-base	Behavior				
			Sec. 1	Sec. 2	Sec. 3	Sec. 4	Sec. 5
	Wheel-trips	*Inches*					
Placing and compacting	0 to 60,000	[1] 0	Unstable	Slightly unstable	Good	Good	Good.
Testing with distributed traffic	60,000 to 80,000	2½	Dusty	Good	do	do	Do.
Do	80,000 to 100,000	½	Raveled	Raveled	Slight raveling	do	Do.
Do	100,000 to 160,000	[2] 0	do.[3]	do.[3]	Raveled [3]	Raveled [3]	Raveled.[3]
Sprinkling and testing with distributed traffic.	160,000 to 180,500	[2] 0	Good	Good	Good	Good	Good.
Compacting bituminous surface treatment	180,500 to 200,500	[2] 0	do	do	do	do	Do.
Testing with concentrated traffic	200,500 to 240,000	½	do	do	do	do	Do.
Do	240,000 to 260,000	2½	do	do	Slightly unstable	do	Do.
Do	[4] 260,000 to 300,000	5	do	do	Unstable	Unstable	Slightly unstable

[1] No water in sub-base. Water admitted to sub-base at 10,000 wheel-trips for 400 wheel-trips, then drained.
[2] No water in sub-base.
[3] Raveling was progressive from secs. 1 to 5.
[4] Wheel loads increased from 800 to 1,000 pounds, at 290,000 wheel-trips.

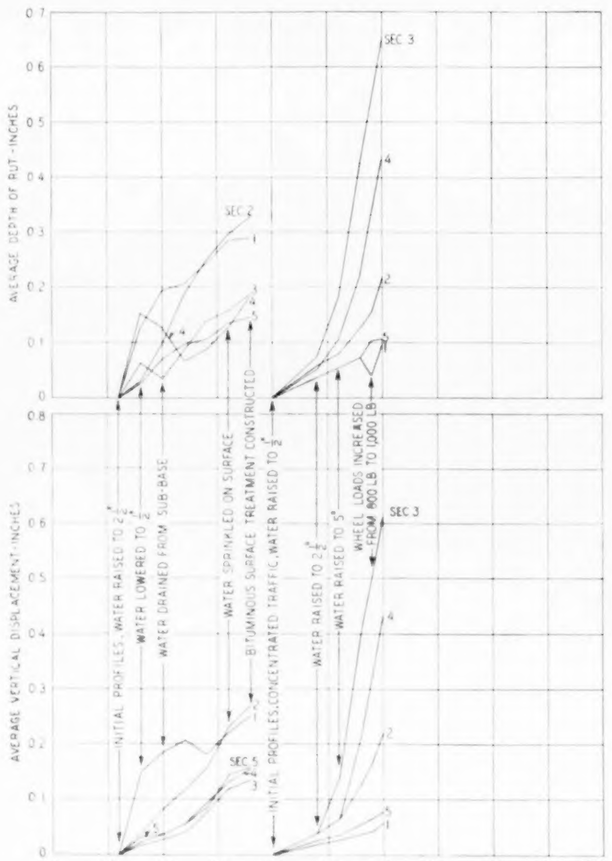

FIGURE 10.—SURFACE DISPLACEMENTS OF SECTIONS OF TRACK 3 AT VARIOUS STAGES OF THE TEST.

Sprinkling was started at 160,000 wheel-trips and continued in a manner similar to that described for tracks 1 and 2. The sections transmitted the water much more readily than did the corresponding sections treated with water-retentive chemicals.

All sections in track 3 were benefited by the application of water to the surface. Although the vertical displacements continued to increase (fig. 10) the surfaces became firm and the aggregates were well bonded under the action of traffic. Figure 12 shows the condition of sections 1 and 3 just prior to the construction of the bituminous surface at 180,500 wheel-trips. Comparison of the sections at this time with their condition as shown in figure 11 clearly illustrates the beneficial effect of the surface water.

A bituminous surface treatment was applied to track 3 at 180,500 wheel-trips. All five materials proved satisfactory as base courses without chemicals. The average vertical displacements and amounts of rutting (see fig. 10) indicated that detrimental movements were not produced until the water had been raised to the 5-inch level and the wheel loads increased to 1,000 pounds.

Sections 1 and 5 exhibited the least amount of movement when tested as base courses. They remained in excellent condition throughout this phase as illustrated in figure 13.

Section 2 moved more than sections 1 and 5 but was still in good condition at the end of the test. Some cracking of the surface treatment between the wheel courses was observed. The condition of these three sections was similar and is illustrated by the view of section 5, figure 13. Sections 3 and 4 showed sufficient rutting at the end of the test to indicate failure. However, this condition was produced only after unreasonably severe test conditions had been imposed. Section 3 in figure 13 is representative of the condition of both sections 3 and 4 at the conclusion of the test.

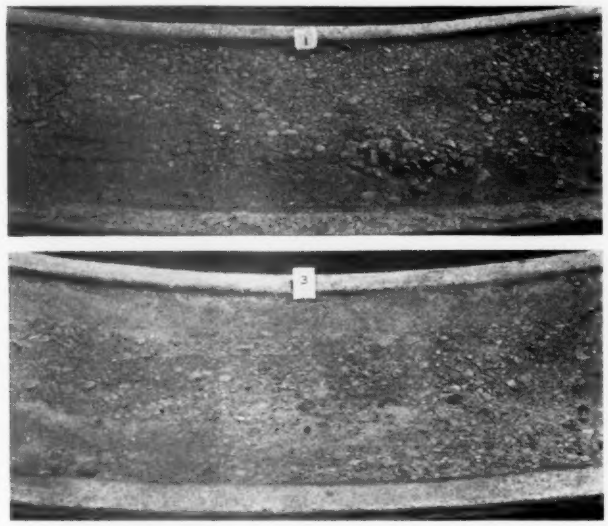

FIGURE 11.—SECTIONS OF TRACK 3 AT 160,000 WHEEL-TRIPS, JUST BEFORE THE FIRST SPRINKLING. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 2; LOWER, SECTION 3. SECTIONS 4 AND 5 WERE IN SLIGHTLY BETTER CONDITION THAN SECTION 3.

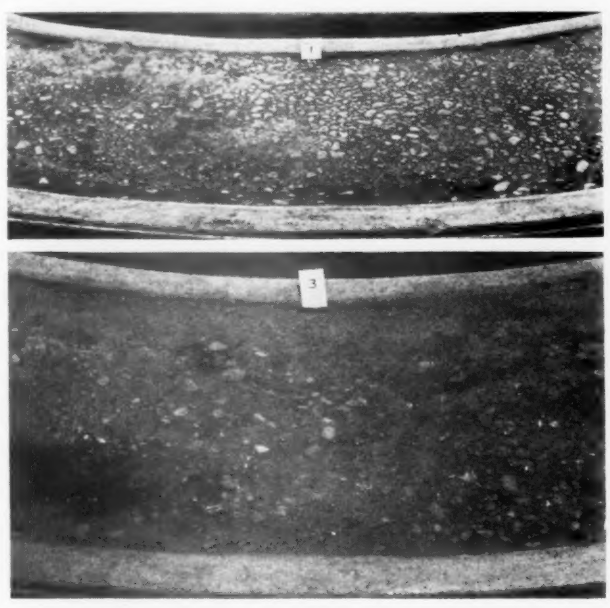

FIGURE 12.—SECTIONS OF TRACK 3 AT 180,500 WHEEL-TRIPS, SOON AFTER SPRINKLING WAS DISCONTINUED. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 2; LOWER, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 4 AND 5.

Track 4: Crusher-run materials.—The five sections of track 4 were constructed of three types of crusher-run materials. Sections 1, 2, and 3 consisted of limestone, granite and slag materials, respectively, as obtained from commercial sources. Section 4 was a

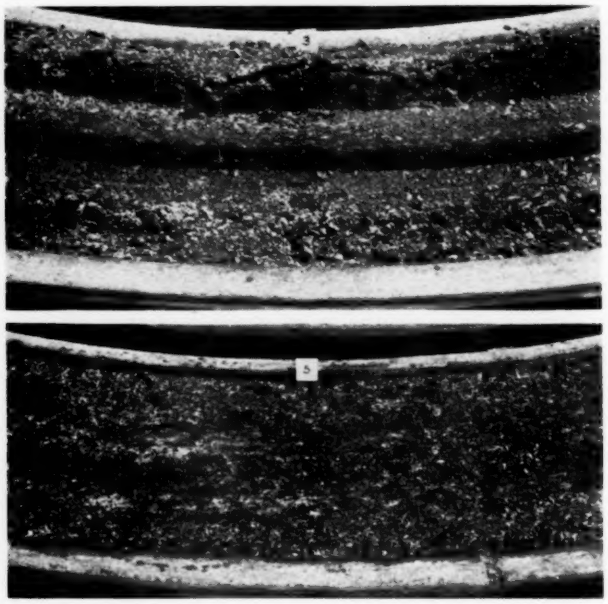

FIGURE 13.—SECTIONS OF TRACK 3 AT THE CONCLUSION OF THE TEST. UPPER, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTION 4; LOWER, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 1 AND 2.

mixture of 90 percent granite and 10 percent slag, and section 5 was a mixture of 90 percent granite and 10 percent limestone. The sections were constructed by dampening and compacting the materials without chemical admixtures.

After the initial compaction period (82,600 wheel-trips) the test was carried out in three distinct steps as shown in table 9.

1. The water level was raised to 2½ inches and distributed test traffic was applied from 82,600 to 182,600 wheel-trips while the water was gradually lowered and finally drained out of the sub-base. Distributed traffic was then continued to 242,600 wheel-trips.

2. The water was again raised to 2½ inches, and a surface application of calcium chloride at the rate of 1½ pounds per square yard was made. Testing with distributed traffic was then resumed while the water was again lowered and finally drained out at 308,800 wheel-trips. Distributed traffic was then continued to 366,000 wheel-trips.

3. A bituminous surface was constructed and concentrated traffic was applied while the water level was

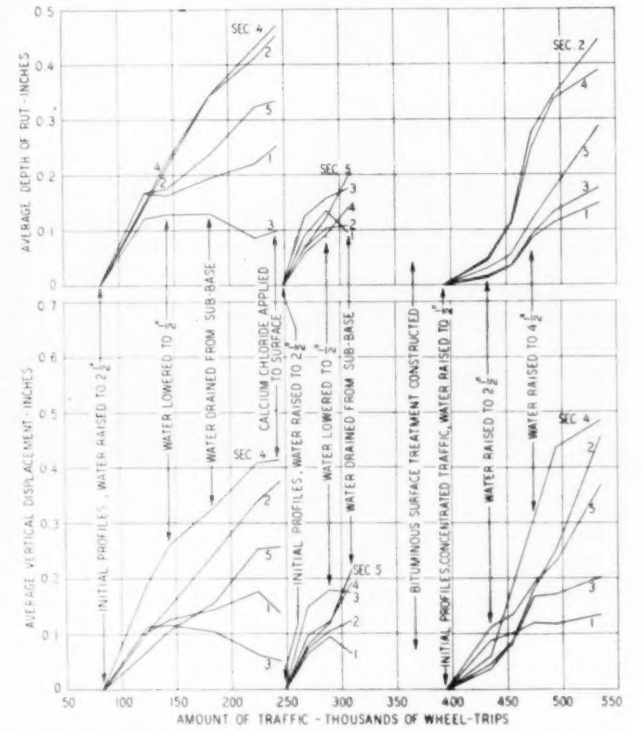

FIGURE 14.—SURFACE DISPLACEMENTS OF SECTIONS OF TRACK 4 AT VARIOUS STAGES OF THE TEST.

gradually increased to a maximum of 4½ inches at 474,300 wheel-trips. An additional 60,000 wheel-trips of concentrated traffic was applied with the water remaining at the 4½-inch elevation

Sections 1 and 3 compacted well and showed no signs of raveling until the water had been completely withdrawn from the sub-base at 182,600 wheel-trips. Sections 2, 4, and 5 on the other hand did not bond or set up well. The surfaces of these sections became loose and dusty even with the water 2½ inches above the bottom of the test course.

Figure 14 shows the amounts of rutting and the average vertical displacements as measured by the profilometers. Both instruments indicated the greatest amount of movement up to 242,600 wheel-trips in sections 2 and 4 and the least movement in section 3. Section 1, figure 15, is representative of both sections 1 and 3. Slight raveling along the curbs was observed as well as

TABLE 9.—*Schedule of operations and behavior of test sections in track 4*

Operation	Traffic	Water level above top of sub-base	Behavior				
			Sec. 1	Sec. 2	Sec. 3	Sec. 4	Sec. 5
	Wheel-trips	*Inches*					
Placing and compacting	0 to 82,600	[1] 0	Good	Slightly unstable	Good	Slightly unstable	Unstable.
Testing with distributed traffic	82,600 to 142,600	2½	do	Raveled	do	Raveled	Raveled.
Do	142,600 to 182,600	½	do	do	do	do	Do.
Do	182,600 to 242,600	[1] 0	Slight raveling	do	Slight raveling	do	Do.
Applying calcium chloride and compacting treated surface.[2]	242,600 o 248,800	[1] 0	Good	Good	Good	Slightly unstable	Slightly unstable.
Testing with distributed traffic	248,800 to 288,800	2½	do	Slightly unstable	do	do	Unstable.
Do	[3] 288,800 to 308,800	½	do	Unstable	do	Unstable	Do.
Do	308,800 to 366,000	[1] 0	do	Slightly unstable	do	Slightly unstable	Do.
Compacting bituminous surface treatment.	366,000 to 394,300	[1] 0	do	Good	do	Good	Good.
Testing with concentrated traffic	394,300 to 434,300	½	do	do	do	do	Do.
Do	434,300 to 474,300	2½	do	Unstable	do	Unstable	Slightly unstable.
Do	474,300 to 534,300	4½	do	do	do	do	Unstable

[1] No water in sub-base.
[2] Sections scarified, sprinkled, compacted lightly, and treated with a surface application of 1½ pounds of calcium chloride per square yard.
[3] Section 5 scarified at 292,200 wheel-trips. Secs. 2, 4, and 5 scarified at 308,800 wheel-trips.

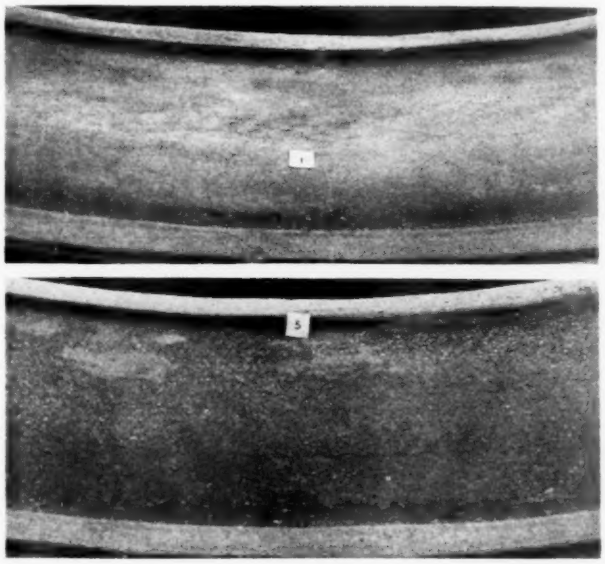

FIGURE 15.—SECTIONS OF TRACK 4 AT 242,600 WHEEL-TRIPS, JUST BEFORE APPLICATION OF CALCIUM CHLORIDE. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 3; LOWER, SECTION 5, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 4.

some wear on the surface. The appearance of section 5, also shown in figure 15, is typical of sections 2, 4, and 5, at 242,600 wheel-trips. The surfaces were loose and unbonded and were wearing badly.

At 242,600 wheel-trips, the sections were scarified lightly and sprinkled. The water level was raised to 2½ inches and calcium chloride was applied uniformly to the surface. Traffic was started on the following day after all calcium chloride had disappeared from the surface.

No dusting or raveling was observed on any of the sections throughout the test period from the time calcium chloride was applied until the bituminous surface treatment was constructed.

The limestone and slag in sections 1 and 3, respectively, remained in good condition during this phase of the test as illustrated in figure 16. The other sections, which were constructed with granite as the predominating constituent, exhibited a marked movement of the surface. This was distinct from the raveling noted earlier in the tests and consisted of shoving and displacement in the direction of traffic. This is well illustrated in figure 16, which shows section 5. The condition described became so bad that it was necessary to scarify and reshape section 5 at 292,200 wheel-trips and sections 2, 4, and 5 at 308,800 wheel-trips.

At 366,000 wheel-trips, the sections were reshaped and compacted and the bituminous surface treatment was applied. Water was brought in contact with the base course and testing with concentrated traffic started at 394,300 wheel-trips.

Sections 1 and 3 remained in good condition throughout the test period. At the end of the test sections 2, 4, and 5, had definitely failed. The displacements for these latter sections were in excess of 0.25 inch and all three sections showed considerable movement under individual wheel-trips. As shown in figure 14 the displacement curves for these three materials rose continuously throughout the test. The displacement curves for sections 1 and 3 on the other hand flattened

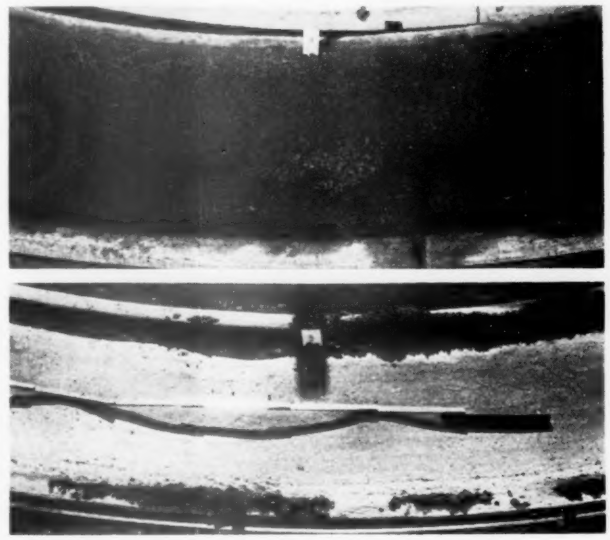

FIGURE 16.—SECTIONS OF TRACK 4 AT 366,000 WHEEL-TRIPS, JUST BEFORE CONSTRUCTION OF THE BITUMINOUS SURFACE. UPPER, SECTION 3, WHICH IS ALSO REPRESENTATIVE OF SECTION 1; LOWER, SECTION 5. SECTIONS 2 AND 4 WERE IN SOMEWHAT BETTER CONDITION THAN SECTION 5.

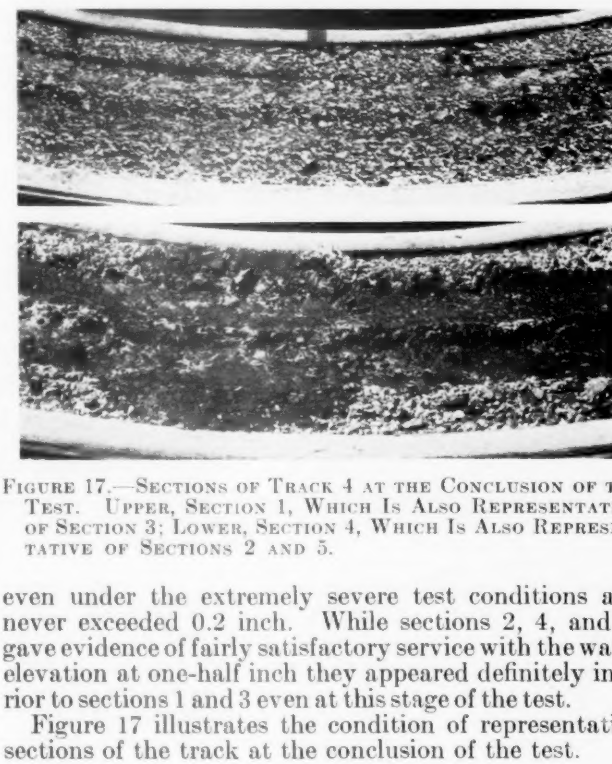

FIGURE 17.—SECTIONS OF TRACK 4 AT THE CONCLUSION OF THE TEST. UPPER, SECTION 1, WHICH IS ALSO REPRESENTATIVE OF SECTION 3; LOWER, SECTION 4, WHICH IS ALSO REPRESENTATIVE OF SECTIONS 2 AND 5.

even under the extremely severe test conditions and never exceeded 0.2 inch. While sections 2, 4, and 5, gave evidence of fairly satisfactory service with the water elevation at one-half inch they appeared definitely inferior to sections 1 and 3 even at this stage of the test.

Figure 17 illustrates the condition of representative sections of the track at the conclusion of the test.

SUMMARY

The test behavior of all the sections in tracks 1, 2, and 3, is correlated in table 10.

Performance as surfaces.—The grading curves for the 5 materials tested in tracks 1, 2, and 3 are shown in figure 18. The shaded band in this figure is drawn to include the A. A. S. H. O. specification requirements for coarse-graded, aggregate-type surfacing materials. These specifications stipulate that the fraction passing the No. 40 sieve shall have a liquid limit not greater than 35 and a plasticity index not less than 4 nor more

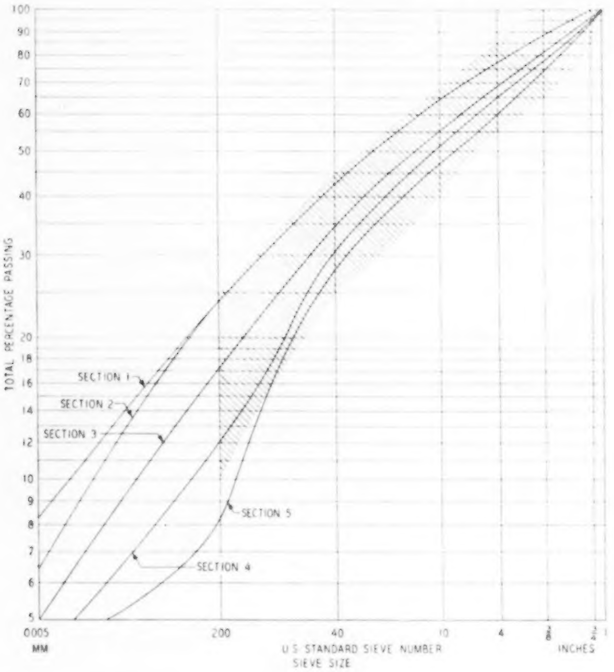

FIGURE 18.—GRADINGS OF MATERIALS IN TRACKS 1, 2, AND 3. SHADED AREA INDICATES ZONE WITHIN WHICH ARE INCLUDED THE SPECIFICATION REQUIREMENTS OF THE A. A. S. H. O. FOR TYPE "B" MATERIAL FOR STABILIZED SURFACE COURSE. EACH GRADING CURVE REPRESENTS THE AVERAGE GRADING OF THE 3 SECTIONS HAVING THE SAME NUMBER DESIGNATION.

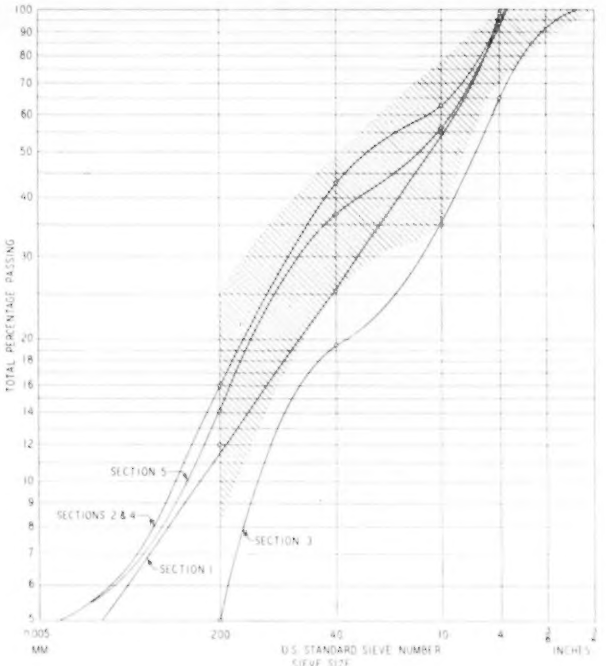

FIGURE 19.—GRADINGS OF MATERIALS IN TRACK 4. SHADED AREA INDICATES ZONE WITHIN WHICH ARE INCLUDED THE SPECIFICATION REQUIREMENTS OF THE A. A. S. H. O. FOR TYPE "C" MATERIAL FOR STABILIZED SURFACE COURSE.

than 9. The maximum plasticity index of any of the mixtures tested was 3 so that while all the mixtures except section 5 conform to the specifications in grading none of them has a plasticity index high enough to meet the specification requirements.

The tests with distributed traffic prior to surface treatment on track 3 without chemical admixture showed that these materials all raveled badly unless they were kept damp by capillary moisture from the ground water table or by water sprinkled on the surface. With decreasing ground water elevation, sections 1 and 2 with the greatest amount of material passing the No. 200 sieve raveled first. Further lowering of the ground water level produced raveling successively in sections 3, 4, and 5, which had dust ratios respectively of 48, 40, and 31. (See table 1.)

TABLE 10.—*Correlation of test behavior of the sections in tracks 1, 2, and 3*

Track No.	Admixture	Sec. No.	Behavior under traffic							
			Without bituminous surface					With bituminous surface		
			Compacting without water in sub-base	Water level 2½ inches	Water level ½ inch	No water in sub-base just before sprinkling	After sprinkling and draining	Water level ½ inch	Water level 2½ inches	Water level 5 inches
1	Calcium chloride	1	Unstable	Slightly unstable.	Good	Good	Slightly unstable.	Good	Good	Good
2	Sodium chloride	1	do	do	Slight pitting	do	do	do	do	Do.
3	None	1	do	Dusty	Raveled	Raveled	Good [1]	do	do	Do.
1	Calcium chloride	2	Good	Good	Good	Good	do	do	do	Do.
2	Sodium chloride	2	do	do	do	Slight raveling	do	do	do	Slightly unstable.
3	None	2	Slightly unstable.	do	Raveled	Raveled	do.[1]	do	do	Good.
1	Calcium chloride	3	Good	do	Good	Good	do	do	do	Do.
2	Sodium chloride	3	do	do	do	Slight raveling	do	do	do	Slightly unstable.
3	None	3	do	do	Slight raveling	Raveled	do.[1]	do	Slightly unstable.	Unstable.
1	Calcium chloride	4	do	do	Good	Slight raveling	Slight raveling	do	Good	Slightly unstable.
2	Sodium chloride	4	do	do	do	do	Good	do	do	Do.
3	None	4	do	do	do	Raveled	do.[1]	do	do	Unstable.
1	Calcium chloride	5	do	Slight raveling	Raveled	do	Raveled	do	do	Do.
2	Sodium chloride	5	do	Good	Good	do	Slight raveling	do	do	Slightly unstable.
3	None	5	do	do	do	do	Good [1]	do	do	Do.

[1] On track 3 traffic was discontinued 20,000 wheel-trips after sprinkling while the sections were still in good condition. Tests prior to sprinkling had indicated that 60,000 wheel-trips with water withdrawn from the sub-base would produce raveling in all sections.

The grading curves for the 5 materials tested in track 4 are shown in figure 19. The shaded band represents the A. A. S. H. O. specification limits for crusher-run surfacing materials. The slag tested in section 3 is coarser than provided for by the specifications. All other materials conform to the specification requirements. Sections 1 and 3, consisting of limestone and slag materials, were satisfactory throughout the tests and were definitely superior to sections 2, 4, and 5 which consisted of granite or largely of granite. The limestone and slag were naturally cementitious and bonded well in the test, whereas the pure granite which was used in section 2 failed to bond and was unstable under traffic. Admixtures of limestone or slag in the amount of 10 percent failed to improve to any appreciable extent the behavior of the crusher-run granite used in this investigation.

Performance as base courses.—The five materials tested in tracks 1, 2, and 3 gave good service as base courses except under the most severe testing conditions. The materials in sections 1, 2, and 3 were finer than the A. A. S. H. O. specification for base courses. The materials in sections 4 and 5, while conforming essentially to the specification, approached its fine limit. Previous investigations had shown that concentrated traffic, with the ground water elevation one-half inch above the bottom of the base course, provides a condition which is sufficiently severe to identify the definitely unsatisfactory materials. In these tests traffic was continued with increased wheel loading after the water had been raised to 5 inches above the bottom of the base course before evidences of failure were produced in tracks 1, 2, and 3.

At the conclusion of these very severe tests the following sections in tracks 1, 2, and 3 were in comparatively poor condition:

Track 1—sections 4 and 5.
Track 2—sections 2, 3, 4, and 5.
Track 3—sections 3 and 4.

In general, mixtures which had from 20 to 25 percent of material passing the No. 200 sieve proved more stable than those having lower dust contents. However, previous investigations[1] have shown that if the fines were plastic this amount of fine material would be detrimental.

[1] See footnote 1, p. 173.

The limestone and slag sections in track 4 gave good service as base courses under all conditions of the test. The granite sections exhibited increasing amounts of movement under traffic with the water one-half inch above the bottom of the base and failed under the severe conditions imposed toward the conclusion of the test.

Densities measured at the conclusion of the test on each track are shown in table 11. Densities obtained in the Proctor or A. A. S. H. O. standard compaction test are also shown in this table. The compaction tests were run on the soil mortar, or that fraction of the material passing the No. 10 sieve. The values shown in table 11 for tracks 1, 2, and 3, are corrected for the material retained on the No. 10 sieve.

With few exceptions, the densities measured in the track were less than the maximum densities computed from the Proctor compaction test. Section 1, which failed to compact readily early in the test in all three tracks, ultimately reached the highest density. Sections 4 and 5 which set up well initially, had densities considerably lower than the other sections in all tracks.

The densities attained in the track by the five crusher-run materials as compared with densities obtained in the vibratory compaction test (see table 12) gave no indication as to their suitability. Their behavior depended on other characteristics.

Effect of chemical treatments.—The effect of the chemical admixtures on the compactibility of the graded materials is shown by the behavior of the test sections during the initial compaction period. Track 1 which contained calcium chloride reached a condition considered suitable for starting the test at somewhat less than one-third the wheel-trips required to produce a similar condition in tracks 2 and 3.

Testing with distributed traffic prior to the construction of the bituminous surface treatment produced less raveling in sections 1, 2, and 3 in both tracks 1 and 2 in which a chemical admixture was used than in the corresponding sections of track 3 which contained no chemical. Section 4 of the chemically treated tracks

TABLE 11.—*Moisture content and density of laboratory compacted aggregates and of circular track sections at conclusion of traffic test*

Track No.	Admixture	Sec. No.	Compacted by Proctor method [1]: Water content based on dry weight	Compacted by Proctor method: Composition by volume: Water	Compacted by Proctor method: Composition by volume: Aggregate	Compacted by Proctor method: Composition by volume: Air voids	Samples cut from track at end of test: Water content based on dry weight	Samples cut from track at end of test: Composition by volume: Water	Samples cut from track at end of test: Composition by volume: Aggregate	Samples cut from track at end of test: Composition by volume: Air voids
			Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Calcium chloride	1	6.1	13.9	86.1	0	5.6	12.8	86.0	1.2
		2	6.8	15.1	84.0	.9	5.3	11.8	84.3	3.9
		3	4.9	11.3	87.4	1.3	4.6	10.5	85.8	3.7
		4	5.4	12.4	86.6	1.0	5.7	12.4	82.0	5.6
		5	4.7	10.8	86.5	2.7	5.9	12.8	81.7	5.5
2	Sodium chloride	1	6.5	14.7	85.3	0	5.1	11.8	87.3	.9
		2	6.1	13.7	84.9	1.4	5.5	12.4	84.9	2.7
		3	5.3	12.2	87.0	.8	4.3	9.8	86.3	3.9
		4	4.5	10.5	88.4	1.1	4.7	10.3	82.8	6.9
		5	4.0	9.4	88.4	2.2	5.1	10.9	80.6	8.5
3	None	1	6.6	14.8	84.9	.3	5.3	12.0	85.5	2.5
		2	6.1	13.9	86.0	.1	5.2	11.6	84.2	4.2
		3	4.7	11.1	88.8	.1	4.8	10.5	82.7	6.8
		4	4.9	11.5	88.5	0	4.9	10.7	82.6	6.7
		5	4.2	9.7	87.6	2.7	5.2	11.1	80.6	8.3
4	Calcium chloride [2]	1					5.4	11.6	79.4	9.0
		2					8.1	16.9	79.1	4.0
		3					9.2	19.7	79.7	.6
		4					6.7	14.3	80.9	4.8
		5					7.1	15.3	81.3	3.4

[1] Compaction test made on portion passing No. 10 sieve and moisture contents and densities calculated for total mixture containing the coarse fraction.
[2] Surface application.

was only slightly better and section 5 no better than the corresponding sections of track 3. Sections 1 and 2 had the highest and section 5 the lowest dust contents.

In track 1, sections 4 and 5, which displayed the greatest amount of raveling, had calcium chloride contents of 0.06 percent when sampled at 118,200 wheel-trips or just before sprinkling. At the corresponding period of test on track 2, 184,000 wheel-trips, the sodium chloride content of section 4 was 0.19 percent and of section 5 was 0.43 percent. (See table 7.)

TABLE 12.—*Densities of crusher-run materials in track compared to densities obtained by vibration*

Sec. No.	Density in track	Density obtained by vibration
	Percent	*Percent*
1	79.4	84.0
2	79.1	79.2
3	79.7	77.9
4	80.9	79.4
5	81.3	80.1

The appearance just before sprinkling of section 5 in the two tracks containing admixtures is shown in figures 3 and 7, respectively. At the corresponding stage of the test, the condition of section 5 in track 3, which contained no admixture, was very similar to that of section 5 in track 1.

While water applied to the surface benefited all sections of track 3, it made section 1 of both the calcium chloride and sodium chloride treated tracks less stable. This loss of stability did not however, extend deeply into the course but was confined to the top inch.

The surface sprinkling failed to improve except temporarily the surface condition of the remaining sections of track 1, but had no detrimental effect on their stability. Aside from its detrimental effect on the surface of section 1, the sprinkling caused an improvement of considerable duration in track 2, which contained the sodium chloride (figs. 7 and 8). A shorter period of drying and less traffic were required to cause raveling to start again in both tracks after leaching than before.

In section 5 of track 1, the amount of raveling caused by only 25,000 wheel-trips subsequent to the surface application of water was decidedly greater than that produced by the 60,000 wheel-trips immediately preceding the sprinkling (figs. 3 and 4). Similarly, in section 5 of track 2, the 40,000 wheel-trips applied after sprinkling and prior to the construction of the bituminous surface treatment had a more detrimental effect than the 80,000 wheel-trips immediately preceding the first application of surface water (figs. 7 and 8).

The chloride content of all sections was reduced by the leaching action of the water sprinkled on the surface as indicated in tables 5 and 7. The calcium chloride content of the sections of track 1 varied from 0.05 percent for section 4 to 0.32 percent for section 1 after the leaching test. In track 2 the sodium chloride content varied from 0.04 percent for section 5 to 0.21 percent for section 1 after leaching.

Determinations at the conclusion of the track tests showed that, with the exception of section 3, the densities of corresponding sections in tracks 1, 2, and 3 were quite similar. In general the sections containing chemicals were slightly denser than the corresponding untreated sections and the densities were roughly proportional to the amount of material passing the No. 200 sieve. The greatest difference was in section 3. In tracks 1 and 2 the final densities of this section were 85.8 and 86.3 percent, respectively, as compared to 82.7 percent where no admixture was used.

CONCLUSIONS

The following conclusions appear to be justified, for the sections considered as surface courses:

1. Nonplastic granular mixtures (tracks 1, 2, and 3) which have the grading requirements of the A. A. S. H. O. specifications for surfacing materials but lower plasticity indexes should give excellent service without chemical admixture when kept damp by capillary moisture or by water sprinkled on the surface. In permanently wet areas, therefore, it appears desirable to waive the minimum plasticity index requirement of 4 as required by the A. A. S. H. O. specification for surface courses, provided the nonplastic materials so admitted have dust ratios of 40 percent or less.

2. It was indicated that in dry locations and without chemical treatment the materials used in tracks 1, 2, and 3 would be subject to raveling and dusting if used as surfaces.

3. Crusher-run limestone and slag were satisfactory as surfacing courses under wet conditions but became dusty under dry conditions. The particular granite used in this investigation was not satisfactory as surfacing because it failed to bond or set up and because it shoved badly when wet.

4. Chemical treatments proved beneficial in the construction of bases for bituminous surfaces. The admixture of calcium chloride expedited compaction. Both calcium chloride and sodium chloride reduced raveling while the base courses were carrying traffic prior to construction of the bituminous wearing course. These results were obtained under conditions of high relative humidity.

5. The presence of 15 to 25 percent of material passing the No. 200 sieve is necessary to prevent the loss of a large part of the water-retentive chemicals when water falls on the surface and percolates through the mixture.

6. A surface application of calcium chloride was effective in reducing dusting and preventing raveling on all five sections in track 4. However, the moisture held near the surface of sections 2, 4, and 5 by the calcium chloride promoted the formation of corrugations to a detrimental extent.

For the sections considered as base courses, the following conclusions appear to be justified:

7. All materials tested in tracks 1, 2, and 3 both with and without chemical admixtures, gave excellent service as base courses except under moisture conditions much more severe than could reasonably be expected in service. It is believed therefore that existing surfaces which meet the A. A. S. H. O. surface course specifications for grading but which are nonplastic in character may be surface treated without altering their composition.

8. The limestone and slag sections of track 4 gave excellent results when tested as bases for bituminous surfacing under all conditions of moisture. Sections 2, 4, and 5, in which the crusher-run granite was the predominating constituent, were inferior to sections 1 and 3 but gave satisfactory service except under unreasonably severe test conditions.

9. Considerable latitude in grading requirements can be permitted when materials such as crusher-run limestone or slag are used for base courses. The natural cementing properties of these materials assist greatly in the formation of stable bases even when the grading is definitely coarser than would be allowed by the present A. A. S. H. O. specifications.

10. Materials that gave trouble during the early compaction period ultimately attained the highest density of any of the sections and gave satisfactory service. This confirms the conclusion reached in previous investigations that early difficulties encountered in compacting materials having acceptable gradings and plasticity indexes need not be taken as an indication of poor quality.

11. Because of its greater density and stability a well-graded sand-clay-gravel material having a low plasticity index is to be preferred to absolutely nonplastic material of comparable grading for base-course construction.

12. The tests indicate that properties other than those revealed by the mechanical analysis and plasticity tests influence the behavior of crushed stone or slag aggregates.

13. It is indicated that the crushed granite with the nonplastic binder used in these tests is not wholly satisfactory either as a surface or as a base. Since satisfactory roads have been built using granite from other sources a more comprehensive investigation of this class of material seems desirable.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF OCTOBER 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 1,740,986	$ 864,785	100.6	$ 7,917,594	$ 3,892,318	259.9	$ 520,090	$ 259,040	10.2	$ 2,724,845
Arizona	972,915	676,732	38.5	1,850,334	1,273,112	93.9	364,101	241,364	20.9	746,615
Arkansas	4,346,672	3,364,023	185.1	831,620	804,785	37.6	1,360,957	719,635	61.1	339,956
California	4,335,690	2,369,920	59.8	3,081,581	1,656,863	56.7	1,568,019	822,299	34.6	2,807,576
Colorado	1,665,527	918,250	41.4	3,311,197	1,844,183	77.8	366,428	206,519	7.8	1,636,253
Connecticut	357,558	176,334	5.1	1,964,755	977,627	19.9				1,237,956
Delaware	516,499	252,872	12.0	1,278,959	626,818	26.4	181,020	90,510	.1	1,019,316
Florida	121,000	59,928	1.4	4,284,214	2,141,882	72.9	505,649	252,825	7.9	2,500,855
Georgia	2,713,300	1,356,650	150.8	6,296,468	3,148,234	346.7	1,459,842	729,921	43.2	5,071,027
Idaho	1,658,103	999,180	82.6	1,155,908	703,715	64.6	274,979	154,602	27.0	1,055,403
Illinois	4,083,413	2,032,669	106.9	8,650,009	4,323,762	167.9	1,272,438	634,825	24.4	2,827,322
Indiana	2,115,702	1,057,851	38.6	6,069,452	3,010,126	135.3	732,436	366,143	13.7	1,865,082
Iowa	2,353,005	1,097,074	108.8	4,769,192	2,099,858	170.4	193,010	91,190	8.0	874,954
Kansas	2,375,055	1,179,822	130.8	2,398,403	1,198,322	115.4	2,915,692	1,457,846	148.1	4,043,296
Kentucky	1,428,269	714,135	48.7	3,668,742	1,832,815	94.4	915,801	457,900	23.1	2,696,361
Louisiana	318,148	156,000	10.8	12,132,849	3,115,133	49.7	1,518,979	742,323	45.1	2,361,588
Maine	1,813,070	906,176	42.1	1,031,510	515,755	24.8	90,670	45,335	2.7	287,017
Maryland	1,249,690	595,711	21.0	2,564,573	1,267,905	37.4	473,000	232,500	8.3	1,816,744
Massachusetts	3,107,045	1,550,834	25.1	713,333	355,469	4.5	1,258,822	627,124	7.5	2,486,225
Michigan	2,471,624	1,206,013	65.5	4,213,089	2,104,400	131.3	682,200	246,200	8.2	2,748,504
Minnesota	3,021,247	1,503,732	198.1	5,395,173	2,675,117	285.6	1,611,402	804,611	70.1	3,081,111
Mississippi	658,400	238,370	35.3	9,163,058	3,448,335	362.5	491,900	227,650	15.4	2,101,461
Missouri	1,452,003	725,302	55.9	5,105,064	2,518,032	180.7	2,742,221	1,138,414	93.0	3,889,219
Montana	1,670,146	944,760	111.4	2,159,501	1,221,799	86.3	1,770,551	1,004,254	113.9	3,485,875
Nebraska	1,159,765	574,441	76.1	6,126,753	3,062,728	571.0	2,045,743	877,990	202.8	2,509,368
Nevada	974,123	836,466	48.7	617,017	529,657	24.7	603,296	518,547	28.5	625,668
New Hampshire	539,946	264,083	18.1	949,318	467,479	21.3	228,372	113,783	9.1	881,230
New Jersey	400,110	191,531	3.6	4,409,098	2,202,999	34.4	180,660	90,330	.1	1,835,924
New Mexico	1,290,907	795,998	108.3	980,780	598,068	38.6	496,131	309,635	38.6	1,128,560
New York	4,660,080	2,298,697	89.5	13,967,219	6,751,448	226.7	1,470,990	602,595	16.1	1,099,572
North Carolina	2,794,090	1,394,965	172.7	6,105,823	3,045,372	322.7	653,610	311,720	38.1	1,335,891
North Dakota	134,060	71,820	28.5	1,297,335	695,199	84.9	2,241,260	1,201,261	244.7	3,363,394
Ohio	2,702,668	1,351,334	32.5	9,116,948	4,489,760	98.0	3,140,160	1,450,580	27.9	5,709,230
Oklahoma	1,223,129	649,003	33.8	2,448,975	1,298,625	99.9	2,633,570	1,382,197	85.4	3,012,834
Oregon	1,687,139	1,005,727	89.1	2,432,864	1,455,960	85.2	1,276,854	600,150	36.4	1,039,348
Pennsylvania	4,601,129	2,283,475	63.0	8,677,516	4,168,217	76.6	3,025,417	1,500,078	37.3	3,147,258
Rhode Island	477,910	238,835	6.9	340,616	170,121	3.2	726,151	362,550	6.5	870,693
South Carolina	1,418,740	639,800	64.1	1,442,574	637,686	22.2	785,140	349,200	60.4	2,145,997
South Dakota	1,823,240	1,007,274	177.8	3,794,559	2,117,860	359.2	1,271,900	716,340	163.1	2,902,674
Tennessee	2,390,148	1,126,512	42.7	3,500,068	1,750,034	86.4	990,674	495,337	18.4	3,425,551
Texas	7,566,986	3,713,589	446.0	8,064,001	4,016,253	322.7	2,011,982	966,505	118.8	5,459,832
Utah	1,802,564	1,290,958	80.9	807,965	593,700	54.2	397,045	200,850	10.0	685,854
Vermont	708,655	347,793	17.8	209,404	104,512	5.5	631,844	315,900	20.9	301,224
Virginia	1,583,530	789,668	52.0	2,664,668	1,283,615	65.4	699,304	344,453	15.2	925,789
Washington	1,443,003	750,367	19.3	3,235,330	1,566,045	29.5	997,102	459,564	18.6	487,088
West Virginia	748,677	411,000	25.8	2,700,515	1,367,495	66.7	723,900	357,645	19.1	1,829,157
Wisconsin	3,845,993	1,887,062	140.3	6,096,440	2,998,880	188.6	393,586	185,145	14.6	1,637,742
Wyoming	1,204,864	752,152	118.0	689,717	422,277	75.3	713,328	450,147	66.3	563,935
District of Columbia				341,624	170,812	2.1	106,700	53,350	1.0	263,338
Hawaii	139,841	66,868	1.0	993,980	480,750	16.4	579,027	286,093	10.1	1,055,906
Puerto Rico	647,050	322,600	13.8	1,282,253	635,060	24.9	83,226	40,975	.6	376,160
TOTALS	94,513,414	50,009,141	3,646.6	193,299,938	93,836,977	5,908.9	52,377,179	26,095,950	2,102.9	102,123,778

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF OCTOBER 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 197,905	$ 97,650	17.2	$ 942,462	$ 383,350	25.6	$ 30,200	$ 15,100	6.8	$ 729,156
Arizona	150,487	108,529	16.5	147,395	105,786	16.9				325,941
Arkansas	765,480	612,922	65.7	183,579	178,910	22.7	73,469	73,414	6.5	151,875
California	662,750	357,967	34.9	499,961	245,274	14.0	191,095	102,335	4.3	651,077
Colorado	518,727	265,180	19.5	478,290	269,039	14.0	36,596	20,626	3.1	31,948
Connecticut				172,794	72,417	2.9	108,041	37,810	.2	251,419
Delaware	80,840	40,420	17.5	71,661	35,831	7.8				232,384
Florida	194,117	96,700	7.3	795,505	393,394	30.3	7,358	3,679		371,271
Georgia	226,952	111,740	28.0	269,282	134,641	31.3	129,939	64,970	18.1	1,072,324
Idaho	214,675	129,195	22.9	319,386	163,267	25.8	130,982	70,634	9.3	73,778
Illinois	841,207	417,975	31.3	1,179,200	529,608	87.8	356,700	177,050	21.0	551,933
Indiana	489,000	244,500	41.7	714,596	356,094	54.3	112,122	56,050	9.4	631,614
Iowa	24,095	11,069	22.9	546,140	257,335	52.5	868,031	406,700	148.3	1,004,703
Kansas	56,428	28,214	26.1	183,802	91,901	20.5	340,325	170,161	7.3	1,291,203
Kentucky	445,912	143,463	44.0	1,057,612	299,582	54.3	521,864	181,918	49.8	223,613
Louisiana	471,353	215,553	41.5	348,970	166,888	27.0	358,993	166,352	29.0	283,778
Maine	324,403	162,130	18.6	161,120	79,474	9.4	19,700	9,850	1.2	9,072
Maryland	204,891	98,787	16.0	80,696	23,048	2.5	186,000	63,355	11.7	350,491
Massachusetts	101,519	50,435	2.4	507,052	251,158	11.1	49,200	24,525	1.6	463,550
Michigan	430,989	209,952	44.7	1,367,782	681,391	95.3	170,000	85,000	10.3	760,511
Minnesota	513,256	254,584	35.3	588,696	294,348	73.8	97,458	48,729	23.4	1,060,844
Mississippi	176,500	88,250	6.8	785,262	396,346	60.7	67,500	33,750	17.0	632,520
Missouri	645,117	311,688	96.0	720,758	342,330	67.3	138,612	52,437	25.8	561,273
Montana	468,607	265,790	48.6	381,003	216,037	23.0	59,718	33,872	6.6	816,329
Nebraska	464,642	222,306	88.3	823,370	404,510	144.7	139,699	69,850	25.4	319,657
Nevada	160,893	136,525	25.0	70,067	60,261	18.1				145,070
New Hampshire	61,156	29,708	2.4	83,280	39,815	3.1				150,441
New Jersey	255,320	125,610	7.1	295,020	146,820	17.3	24,500	12,250		509,585
New Mexico	466,270	286,858	42.1	27,020	15,690		361,210	146,391	26.9	80,519
New York	918,636	454,559	45.9	2,393,105	1,149,608	86.7	273,200	95,750	4.1	229,233
North Carolina	711,294	355,625	57.7	725,030	362,515	73.7	35,240	12,500	2.3	316,205
North Dakota	115,030	61,606	8.3	37,500	20,100		111,270	59,617	10.9	819,207
Ohio	230,820	115,410	15.2	900,170	455,550	39.9	802,000	401,000	27.8	1,323,392
Oklahoma	81,838	38,943	.8	336,696	179,153	16.8	470,655	250,428	36.9	858,921
Oregon	551,886	310,902	59.9	271,962	126,380	31.2	14,696	8,820		292,800
Pennsylvania	1,905,307	940,977	109.3	1,096,322	542,056	38.5	370,074	185,037	13.3	211,879
Rhode Island	93,827	46,890	2.2	81,236	40,618	.2	36,060	18,030	.4	78,277
South Carolina	562,159	228,890	56.9	22,620	10,179		303,500	126,600	22.2	220,251
South Dakota	3,830	2,100	4.0	23,396	12,878					1,043,072
Tennessee	732,508	313,954	27.1	226,796	113,398	5.3				759,186
Texas	1,735,044	856,416	198.2	887,272	428,005	83.9	313,260	135,950	40.9	899,503
Utah	190,570	110,765	30.2	48,830	24,098	9.2	115,770	44,000	5.2	153,199
Vermont	126,051	62,026	4.5	187,872	61,587	7.3				52,851
Virginia	525,334	255,171	57.3	232,980	114,854	14.4	310,590	136,228	17.9	172,598
Washington	473,395	247,383	26.0	290,290	151,918	22.9	103,829	53,400	11.2	215,301
West Virginia	145,150	72,575	8.3	13,015	6,507		203,901	101,951	10.8	411,464
Wisconsin	523,087	260,059	27.1	591,300	295,162	9.3	471,585	221,418	7.3	473,606
Wyoming	464,992	288,144	26.0	159,218	100,513	10.3	112,112	65,156	19.6	64,172
District of Columbia				101,892	50,446	1.1	15,800	7,900	.2	14,779
Hawaii	90,660	45,330	3.7	205,590	102,795	4.6	179,480	89,705	6.4	82,170
Puerto Rico				224,464	109,130	12.8	55,188	27,140	2.1	60,233
TOTALS	19,794,909	10,191,425	1,638.9	22,859,317	11,091,995	1,482.1	8,877,522	4,167,438	702.5	22,490,178

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF OCTOBER 31, 1939

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$ 515,350	$ 503,059	5	1		$ 743,712	$ 742,184	11			$ 43,508	$ 43,300	1	1	2	$ 816,092
Arizona						518,061	515,813	6								209,120
Arkansas	189,891	189,891	3			669,853	663,348	3			23,968	23,968	2		8	593,191
California	605,661	605,611	5			1,137,816	1,136,771	6		1	137,560	137,560	2		1	1,243,433
Colorado	309,307	309,305	3		11	306,992	306,992	2			48,514	44,754			14	791,132
Connecticut						172,722	161,008		1		21,333	21,333			7	829,223
Delaware						9,150	9,150	2			2,320	2,320			1	513,891
Florida						624,747	620,249	4			11,800	11,800			3	1,034,542
Georgia	56,530	56,530	3			405,396	405,396	4	1		446,616	446,616	6	3	21	1,957,478
Idaho	191,612	160,443	3			122,880	122,518	1								466,886
Illinois	1,846,535	1,845,675	11	3	43	1,828,339	1,689,967	10	1	21	184,242	173,570	3		24	1,979,000
Indiana	739,703	739,703	3	1	45	398,555	398,555	1	1	33	423,614	423,614	1	1	52	740,558
Iowa	340,647	321,200	10		2	279,344	242,456	4		40	755,748	707,700	1		180	831,318
Kansas	697,393	697,393	8		4	655,704	655,704	7		1	354,569	351,643	5		7	778,718
Kentucky	380,015	380,015	6	4		396,061	396,061	6			771,423	771,423	5		13	375,135
Louisiana	122,838	122,830	2			824,494	770,989	7			317,665	317,659	10			584,469
Maine	327,109	327,109	3	2		20[illegible] 728	208,728	2	1							236,310
Maryland	24,510	15,402				240,795	240,795	2		2	46,200	46,200			13	925,099
Massachusetts	265,259	264,538	1	2		257,307	256,764	3			14,320	14,320	1			1,711,447
Michigan	386,326	386,326	3	2	7	855,015	855,015	5		3	475,081	475,081	3		29	1,309,120
Minnesota	254,481	251,067	1	4	6	1,237,359	1,217,528	9	2	7	509,223	336,263	3		6	1,117,339
Mississippi						611,373	611,373	8			37,300	37,300	1			889,528
Missouri	65,589	64,284	1			1,266,356	1,266,356	7	2		680,534	655,256	3	4		1,324,064
Montana	614,653	614,653	6			448,927	333,846	6			80,000	80,000	1			204,589
Nebraska	381,275	380,675	13			781,157	781,157	12	1	2	269,075	269,075		1	45	511,406
Nevada	156,993	156,993		1	3	37,305	37,305		1	5	11,577	11,577			5	114,944
New Hampshire	48,623	48,202	5		1	113,962	113,879	3			45,804	45,804	2			313,600
New Jersey	7,140	7,140			1	730,316	730,316	2	3		150,090	150,090	1			1,289,255
New Mexico	59,805	59,805	2			15,276	15,276				2,572	2,572			1	692,665
New York	1,172,330	1,168,630	2	5		2,360,212	2,182,492	10	9		200,820	200,120	1	1		3,453,396
North Carolina	668,844	636,144	4	2	18	876,400	874,000	9	3	8	444,735	444,735	2	1	39	586,364
North Dakota	105,450	105,450	3	1		818,489	770,087	9			75,960	75,960	1			391,201
Ohio	308,640	293,640	6			1,449,673	1,378,721	8	3		917,090	917,090	6		4	2,473,570
Oklahoma	266,955	266,955	3		32	187,025	187,025	3		11	307,500	294,700	8	1	8	1,924,197
Oregon	40,500	39,002				266,498	265,204	3								311,060
Pennsylvania						2,344,004	2,132,105	6	4		520,652	312,200	2		2	4,218,923
Rhode Island	327,613	327,613	1	2		111,178	111,178		1							152,459
South Carolina	177,614	144,232	4	2	7	590,456	568,120	6	3		179,375	179,375		2	26	782,723
South Dakota	72,757	72,757		1	8	336,475	336,475	4	2	9	47,550	47,550	1			995,433
Tennessee	73,600	73,600		1	1	799,806	799,806	3	3	2	6,760	6,760			2	1,332,344
Texas	1,204,696	1,173,640	12	2		2,321,258	2,256,842	18	1		51,150	51,150			26	1,913,207
Utah	111,841	111,778	2		32	146,758	146,758	1		53	161,010	161,010			58	177,522
Vermont	35,558	30,246			7	1,462	1,462				118,940	118,940		1		200,249
Virginia	207,404	207,404	2		16	515,975	423,075	7	2		129,256	129,256	1	1	4	909,331
Washington	126,622	126,621	1		8	209,590	208,180	2	1	2	208,720	208,037	1	2	2	362,668
West Virginia	64,417	64,417	2			310,434	294,674	5			24,200	24,200	1		3	959,985
Wisconsin	480,877	478,594	6		2	1,056,194	1,012,263	9	1	6	684,738	625,617	3	2	6	650,823
Wyoming	40,626	40,470	1		7	98,543	98,543		1							516,862
District of Columbie						292,412	258,868	1			74,400	74,400				47,053
Hawaii	52,950	50,320	1			132,850	132,850	3	1		6,216	6,216			1	353,234
Puerto Rico	49,040	48,840	1			345,312	343,310	8								426,676
TOTALS	14,175,079	13,968,202	148	36	261	31,468,706	30,287,537	248	49	206	10,023,728	9,478,114	78	21	613	47,522,832